Progress Report
July 2004 – Feb 2005
(NA03OAR4310063)

Understanding the Spatio-Temporal Variability of the North American Monsoon: Implication to Water Resources Management in the South Western US

Rajagopalan Balaji, University of Colorado

<u>Proposed Activities for Year 2 (July 2004 – June 2005):</u>

1. *Spatio-Temporal Variability*. Further investigation of the spatio-temporal variability of the NAMS with station data, including correlations with antecedent winter hydroclimatology and large-scale climate and an analysis of the spatial shift in the strength of the monsoon
2. *Physical Mechanism*. Diagnostic of water cycle data and the links to dominant modes of hydroclimate variability, in order to understand the physical mechanisms or moisture transport etc.
3. *Hydrologic Prediction.* Develop a streamflow prediction model using semi-parametric prediction techniques.
4. *Management Issues.* Determine/ compile Rio Grande management issues to incorporate in this study.

<u>Year 2 Activities Status:</u>

Investigations of the spatio-temporal variability of the North American Monsoon aimed to address the following questions: (a) How does the NAMS and the associated hydrologic cycle vary in space and time? (b) What large-scale climate forcings (SST/SLP patterns, ENSO, PDO, etc.) modulate their variability and predictability? (c) Is there a connection between the summer monsoon and the preceding winter precipitation (i.e. land-ocean temperature gradient)—if so, is it robust enough for predictive purposes? (d) How does the variability of NAMS affect management of rivers in the NAMS region?

Analysis Methods:
Preliminary analysis of spatio-temporal variability utilized the station data for Arizona and New Mexico. Specifically, the following analyses were performed:

- Trend analysis of total monsoonal precipitation for Arizona and New Mexico
- Trend analysis of timing of peak precipitation to determine shift in the timing of the monsoon
- Annual cycle analysis of streamflow
- Relationship between summertime precipitation and summertime streamflow
- Relationships between spring precipitation/ PDSI and monsoonal precipitation/streamflow

- Climate composites for high and low precipitation and streamflow years

Results:
A brief summary of preliminary results and select figures are presented here.

Spatial Shift in the Strength of the Monsoon:

In this analysis we performed a linear regression on the station data of all co-op stations in the New Mexico and Arizona region. This analysis was performed for July and August separately, and for the total precipitation in July and August together. Figure 1 displays the results of the analysis.

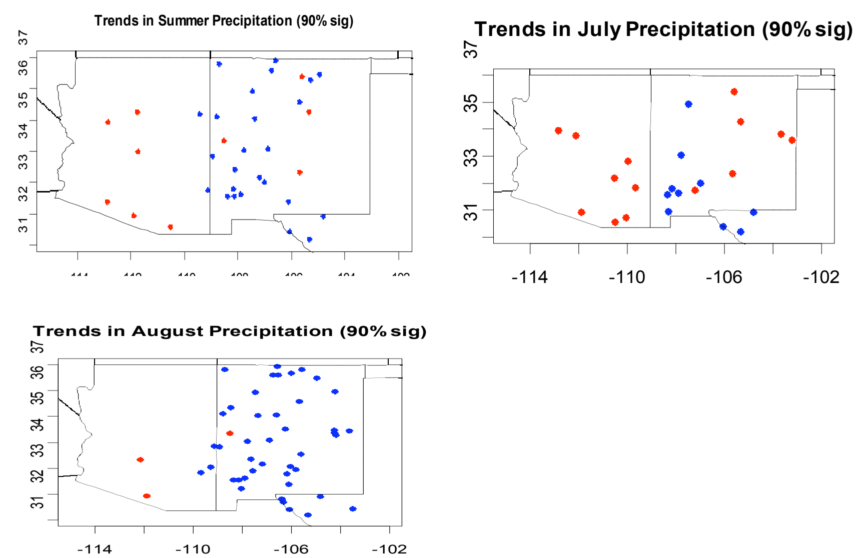

Figure 1. Trends in station data based on linear regression. Color indicates the 90% significant direction of trend (blue indicates increasing precipitation, red indicates decreasing precipitation).

The results for total summer precipitation (July and August together) show an increasing trend in precipitation in New Mexico and a decreasing trend in Arizona. These results corroborate those of McCabe and Clark (2003). The number of stations with statistically significant trends was greatest for August in New Mexico. While trends in July in New Mexico are mixed, August shows a definite increase in precipitation. These differences could potentially be related to a shift in the timing of the peak of the monsoon in New Mexico. This was investigated and is described below.

Figure 2 shows the Hovmuller diagram for the August precipitation. The cooler colors indicate more precipitation, the warmer colors indicate less precipitation. The precipitation has been averaged over 1 degree longitudinal bands over the New Mexico and Arizona region (x-axis). The y-axis shows how the precipitation changes over time.

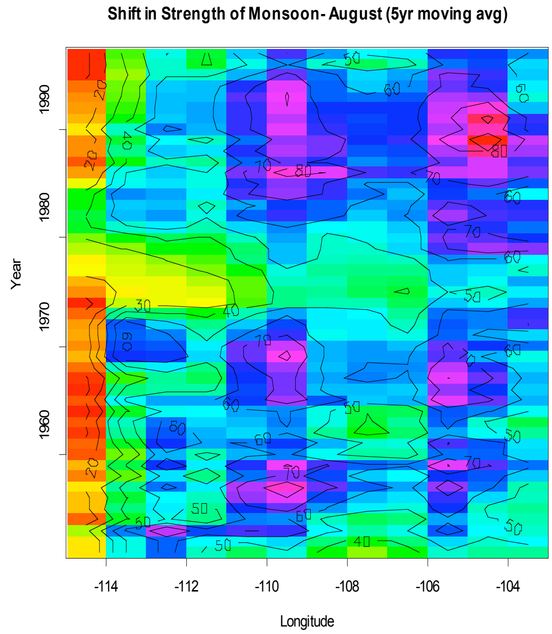

Figure 2. Changes in precipitation at averaged 1degree longitudinal bands over time. Cooler colors indicate more precipitation, warmer colors indicate less.

The results corroborate those shown in figure 1. Precipitation is less during the recent period in the western region (mainly Arizona) and greater in the eastern region (mainly New Mexico). The diagram also shows that the trend is not steady, but rather the precipitation appears to shift after a relatively dry spell in the mid-1970s.

These results have important implications for understanding predictability.

<u>Shifts in the Timing of the Monsoon:</u>

To investigate the shift in the monsoon timing, we performed a trend analysis on the timing of the peak of the monsoon. Here, the peak of the monsoon is defined as the Julian date when 50% of total monsoonal rainfall has been reached. The results shown in figure 3 illustrate that the monsoon seems to be occurring later in both Arizona and New Mexico in recent decades. Significant shifts of over 10 days (over the 50 year time period) are seen in more than 40 stations. These timing shifts can be very important to sub-seasonal water resources management (i.e., timing the release of water from the reservoirs).

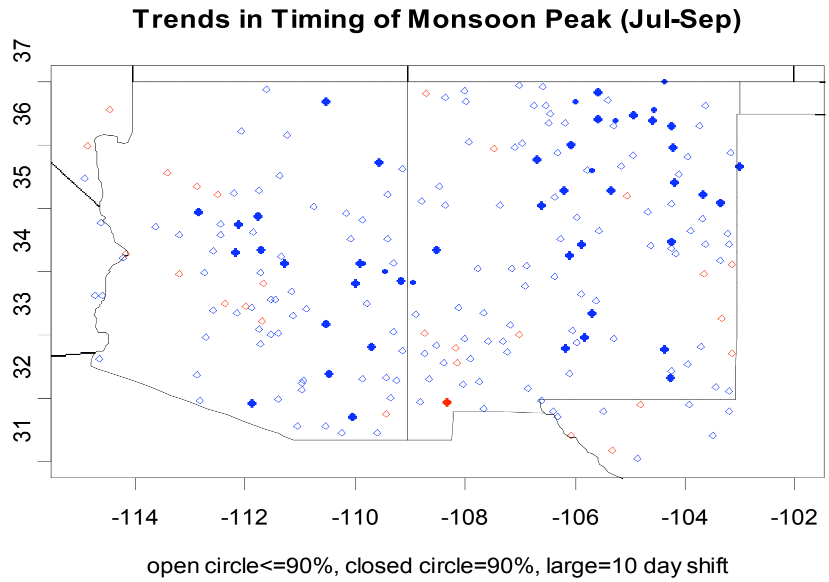

Figure 3. Trend in the timing of the peak of the monsoon.

One possible explanation for the delay in the peak of the monsoon is that it could be related to trends in the antecedent land surface moisture condition ([i.e., spring precipitation or the Palmer Drought Severity Index (PDSI)] in the monsoon region. Figure 4 shows that March to May precipitation in Arizona and New Mexico has been increasing over the past 56 years. Trends in the PDSI also show that the moisture in this region has increased in recent decades. An increase in soil moisture at the beginning of the monsoon season could lead to a delay in monsoonal precipitation because more solar energy is spent evaporating the increased soil moisture before warming the land to set up the land-ocean gradient necessary for monsoonal precipitation.

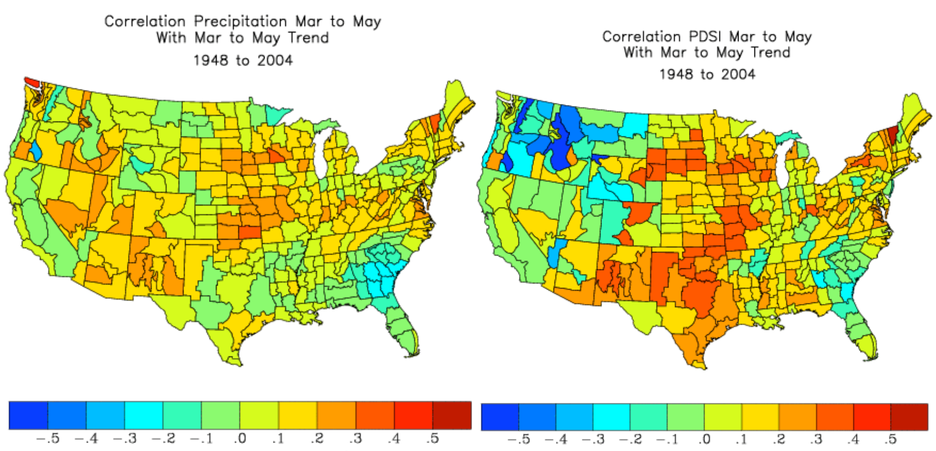

Figure 4. Trends in spring (Mar-May) precipitiaton (left) and PDSI (right).

Streamflow Analysis

A preliminary analysis of streamflow in the NAMS region was performed. In this, we examined the flows from Gila River in southwestern New Mexico. The annual cycle (figure 5) shows two distinct peaks in streamflow—one during early spring, presumably due to the melting of snow accumulated during the winter months, and one in late summer, presumably due to monsoonal precipitation. The summertime streamflow contributes significantly to the total annual streamflow, though not as much as that from the spring runoff. Thus, streamflow resulting from monsoonal precipitation has important implications to water management.

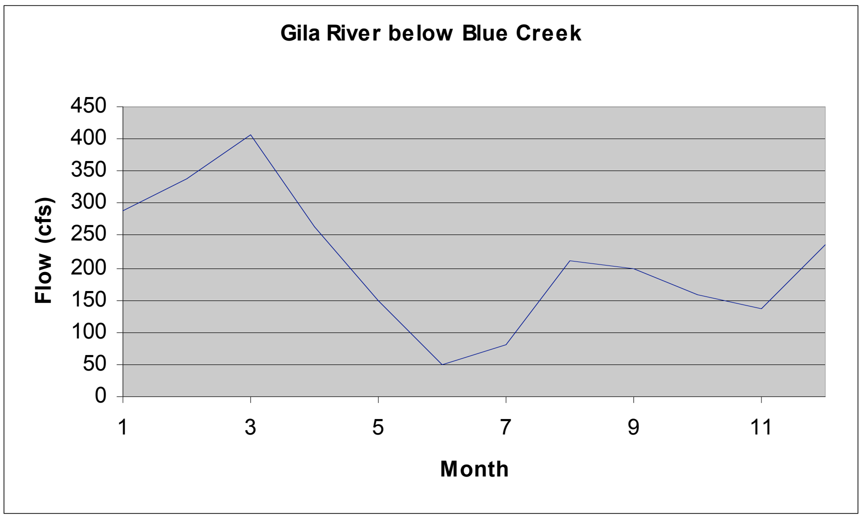

Figure 5. Annual cycle for Gila River, New Mexico.

The relationship between summertime (July-Aug) precipitation, from the climate division that includes the watershed and, summertime (Aug-Sep) streamflow is shown in figures 6 and 7. Notice the interesting nonlinearity in Figure 6 between the precipitation and streamflow – consistent with the linearity in the log-log scale (Figure 7). This non-linear relationship can be explained as follows: relatively small amounts of rainfall are infiltrated leaving little water for runoff and, thus contribute little to the streamflow; larger precipitation amounts above some infiltration threshold will likely have saturated the ground and will contribute significantly to the runoff and streamflow. Also, it is likely that the intense, short rainstorms typical of the monsoon region may result in overland flow more quickly than less intense storms.

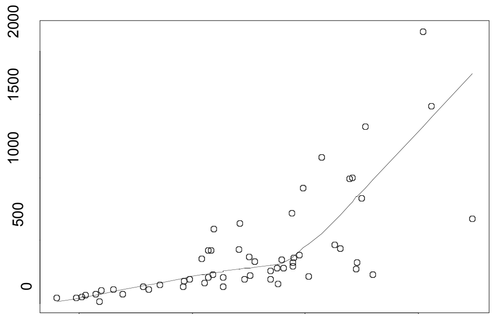

Figure 6. Nonlinear relationship between summertime precipitation (NM climate division 4) and summertime streamflow (Gila River below Blue Creek).

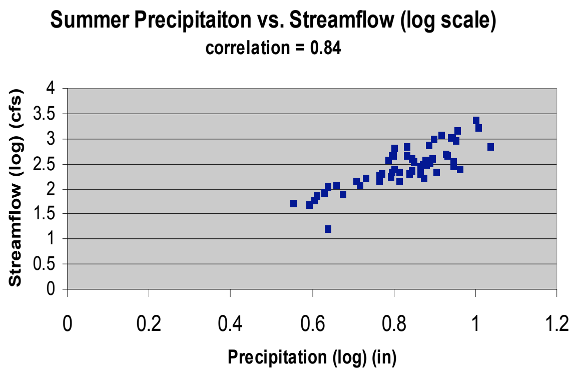

Figure 7. Correlation between log of summertime precipitation (NM climate division 4) and log of summertime streamflow (Gila River below Blue Creek).

The relationship between spring (Feb-Apr) and summer (Aug-Sep) streamflow is shown in figure 8. The streamflow is from the Gila River below Blue Creek. These results show that low summer streamflow is not related to the magnitude of the preceding spring runoff. However, higher summer streamflows occur most often when preceded by a low spring runoff. These results support the hypothesis that that lower winter precipitation and resulting spring runoff lead to increased monsoonal precipitation and streamflow. Below average winter precipitation and spring runoff results in below average soil moisture the following spring and summer. With less moisture to evaporate, the hypothesis states that the land heats up more than average, thus increasing the land-ocean gradient. When air moisture is not limiting, higher land-ocean gradients result in higher monsoonal precipitation.

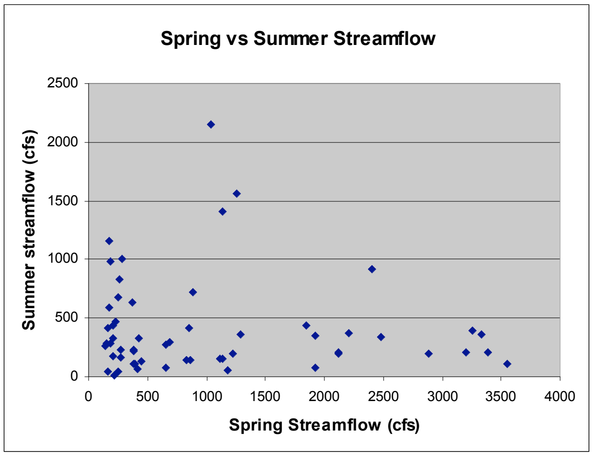

Figure 8. Correlation between log spring (Feb-Apr) summertime (Aug-Sep) streamflow for the Gila River below Blue Creek.

To further investigate the hypothesis relating antecedent soil moisture to monsoonal precipitaiton, we correlated the spring (March to April) precipitation and PDSI with PC1 of the July precipitation and the Gila River summer streamflow. (See figure 9.) The results for the precipitation show a negative correlation between the spring PDSI and the monsoonal precipitation in July, and also between the spring precipitation and the monsoonal precipitation in July. The results for the streamflow in the Gila River show this general trend as well, the the correlations are not negative for all the climate divisions in New Mexico.

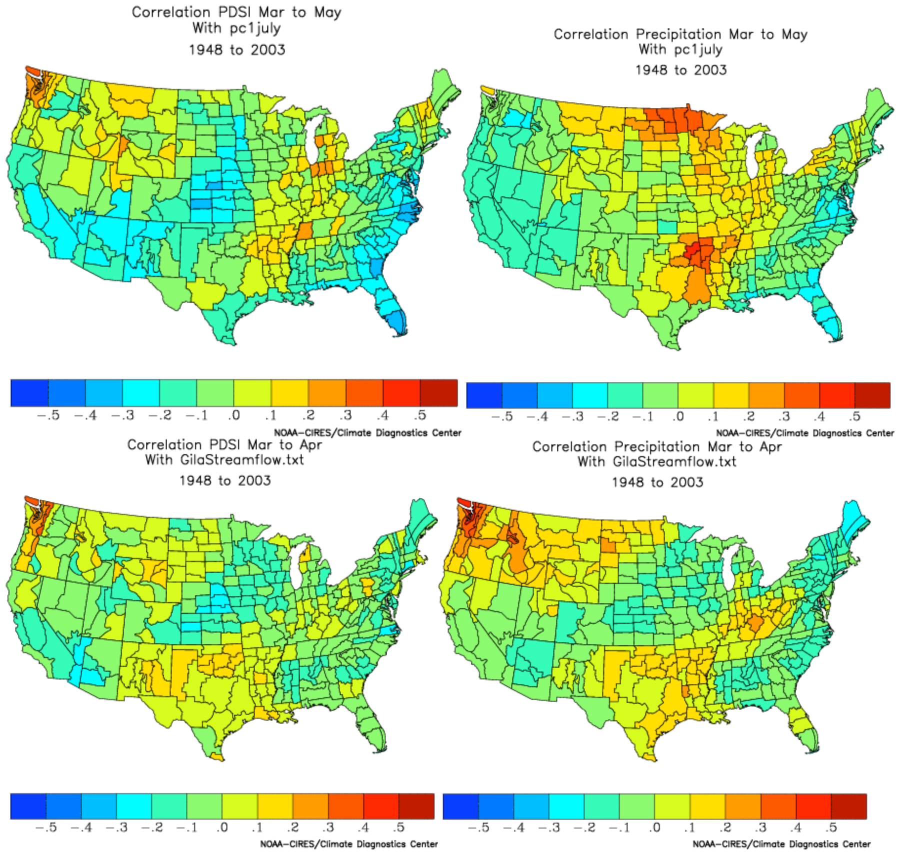

Figure 9. Correlations between spring (March to April) PDSI (left) and precipitation (right) and the PC1 of the july precipitation (top) and the Gila River summer streamflow (bottom).

Further analysis of streamflow is currently underway.

Links to Large-Scale Climate

A composite analysis of sea surface temperatures was performed for high and low monsoonal precipitation years and high and low streamflow years. This analysis was done separately for July and August. Figure 10 presents the high minus low composites. Precipitation was from New Mexico climate division 4 and streamflow was from the Gila River below Blue Creek. The results show that the monsoonal precipitation and resulting streamflow are related to heating in the tropics. The SST pattern, however, is not identical for precipitation and streamflow. SSTs in high streamflow years are warmer than average from the coast of South America out to the date line; the converse is true for low streamflow years. SSTs in high precipitation years, however, are warmer than average near the South American coast, but cooler than average close to the date line; the converse is true for low precipitation years.

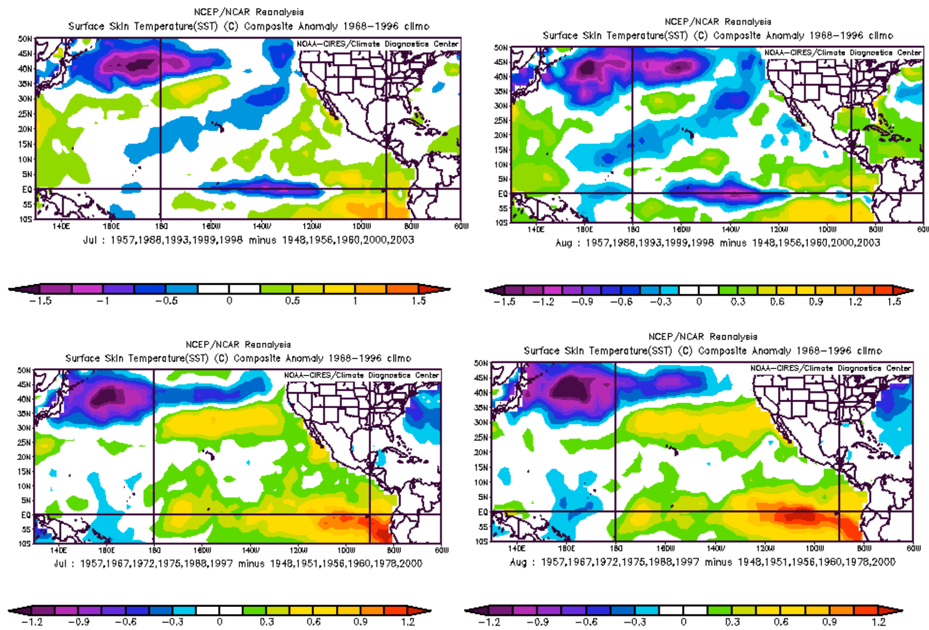

Figure 10. Composites anomalies of July (left) and August (right) SSTs in high minus low precipitation (top) and streamflow (bottom) years.

Figure 11 shows the composite anomalies of winter SSTs preceding high minus low summer streamflow years. The figure shows that summer streamflow is related to the heating in the tropics in the preceding winter months, indicating that ENSO could be a good long-lead predictor for forecasting summer streamflow.

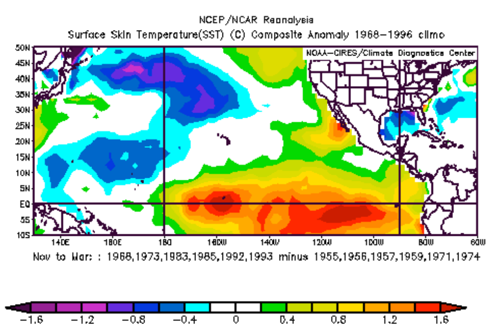

Figure 11. Composites anomalies of winter SSTs in high minus low summer streamflow years.

To investigate whether the position of the heating in the ocean affects the location of precipitation on the land, we performed a composite analysis of summertime SSTs in high monsoon years for New Mexico and high monsoon years for Arizona. Figure 12 shows that monsoonal precipitation in both Arizona and New Mexico is linked to tropical SSTs in July and August. It is interesting to note that the location of the heating in the tropics is different for Arizona and New Mexico. The heating for Arizona is closer to the South American continent, while the heating for New Mexico is close to the date line. Further analysis of this potential relationship is currently underway.

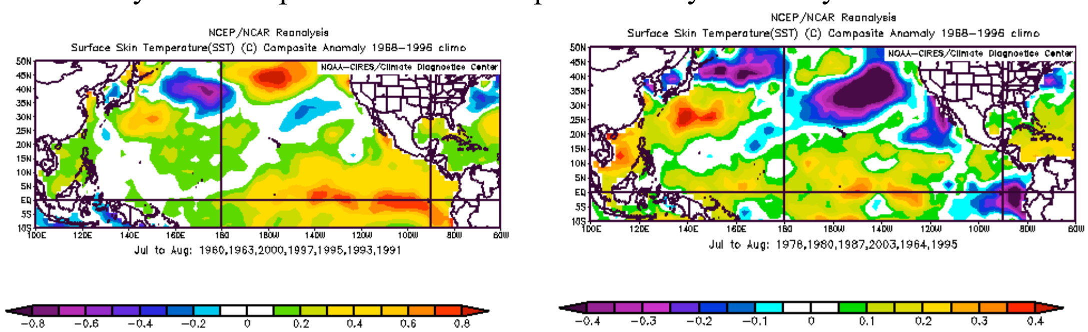

Figure 12. Composites anomalies of July to August SSTs in high monsoon years in Arizona (left) and New Mexico (right).

Future analysis is currently underway to investigate whether the position of the heating in the ocean affects the location of precipitation and resulting streamflow on the land. Also, an analysis of climate composites for precipitation over the entire monsoonal region is being performed.

Tasks From Year 2 (July 2004 – June 2005) Still in Progress:

1. *Understand the role of antecedent winter/spring precipitation and/or spring runoff.* Perform additional analysis of antecedent winter/spring hydroclimatology and large-scale climate.
2. *Further analysis of streamflow variability during summer and spring in the SW monsoon region*. In general and particularly for basins with management issues.
3. *Hydrologic Prediction.* Develop a hydrologic streamflow and monsoon prediction model using semi-parametric prediction techniques.
4. *Management Issues.* Determine/ compile Rio Grande or Pecos management issues to incorporate in this study.

Year 3 Proposed Activities (October 2005- Sept 2006):

1. *Coupling of hydrologic prediction with decision support system to analyze different management strategies.*

* Figures 4, 9, 10, 11 and 12 were generated using the CDC NOAA interactive plotting web tool.